

What I claim is:

1. A method of welding a solid consumable material to a base material within a welding zone comprising:

bringing a working surface of the consumable material into contact with a base surface of the base material, the working surface being urged against the base surface by a contact force, the contact force being applied generally along an axis substantially normal to the base surface;

moving the working surface relative to the base surface while maintaining the contact force, thereby generating frictional heating within the welding zone;

causing an electrical current to flow through the base material, the electrical current flowing through or closely adjacent the welding zone, thereby generating resistance heating within the welding zone;

wherein a cumulative heating of the welding zone by the frictional heating and the resistance heating, in combination with the contact force, are sufficient to welding a portion of the consumable material to the base surface within the welding zone, thereby forming a first weld spot; and

withdrawing the consumable material from the base surface, thereby forming a new working surface.

2. A method of welding a solid consumable material to a base material according to claim 1, wherein:

the working surface of the consumable material is moved relative to the base surface using at least one motion selected from a group consisting of rotation, reciprocation, translation, oscillation, orbital rotation and arcuate motions.

3. A method of welding a solid consumable material to a base material according to claim 1, further comprising:

moving the working surface of the consumable material along the base surface in a weld direction to extend the weld spot and form an elongated weld bead, wherein the working surface has a maximum dimension  $D_m$  in a direction perpendicular to the weld direction and wherein

the elongated weld bead has

a width  $W$ , the width being less than about twice  $D_m$ , and

a length  $L$ , the length being substantially larger than  $D_m$ .

4. A method of applying a metallic material to a conductive base material according to claim 3, wherein:

the elongated weld bead is straight, curved or a combination of straight and curved portions.

5. A method of welding a solid consumable material to a base material according to claim 1, further comprising:

moving the working surface of the consumable material along the base surface in a weld direction to extend the weld spot and form an elongated weld bead, wherein the working surface has a maximum dimension  $D_m$  in a direction perpendicular to the weld direction and wherein

the elongated weld bead has

a width  $W$ , the width being greater than about twice  $D_m$  and

a length  $L$ , the length being substantially larger than  $D_m$ .

6. A method of applying a metallic material to a conductive base material according to claim 5, wherein:

the elongated weld bead is straight, curved or a combination of straight and curved portions.

7. A method of welding a solid consumable material to a weld region on a base material comprising:

preheating the weld region;

bringing a working surface of the consumable material into contact with a base surface of the base material, the working surface being urged against the base surface by a contact force, the contact force being applied generally along an axis substantially normal to the base surface;

moving the working surface relative to the base surface while maintaining the contact force, thereby generating frictional heating within the welding zone; and

causing an electrical current to flow through the base material, the electrical current flowing through or closely adjacent the welding zone, thereby generating resistance heating within the welding zone;

wherein a cumulative heating of the welding zone by the preheating, the frictional heating and the resistance heating, in combination with the contact force, are sufficient to cause welding of a portion of the consumable material to the base surface within the welding zone.

8. A method of welding a solid consumable material to a weld region on a base material according to claim 7, wherein:

the preheating of the weld region is achieved using at least one heating method selected from induction heating, plasma arc heating, electric arc heating, tungsten inert gas (TIG) torch heating, laser heating and electron beam heating.

9. A method of welding a solid consumable material to a weld region on a base material comprising:

preheating a portion of the consumable material, the preheated portion including a working surface;

bringing the working surface of the consumable material into contact with a base surface of the base material, the working surface being urged against the base surface by a contact force, the contact force being applied generally along an axis substantially normal to the base surface;

moving the working surface relative to the base surface while maintaining the contact force, thereby generating frictional heating within the welding zone; and

causing an electrical current to flow through the base material, the electrical current flowing through or closely adjacent the welding zone, thereby generating resistance heating within the welding zone;

wherein a cumulative heating of the welding zone by the preheating of the consumable material, the frictional heating and the resistance heating, in combination with the contact force, are sufficient to cause welding of a portion of the consumable material to the base surface within the welding zone.

10. A method of welding a solid consumable material to a weld region on a base material according to claim 9, wherein:

the preheating of the portion of the consumable material is achieved using at least one heating method selected from induction heating, plasma arc heating, electric arc heating, tungsten inert gas (TIG) torch heating, laser heating and electron beam heating.

11. A method of welding a solid consumable material to a weld region on a base material comprising:

preheating the weld region;

preheating a portion of the consumable material, the preheated portion including a working surface;

bringing the working surface of the consumable material into contact with the weld region on a surface of the base material under a contact force, the contact force being applied generally along an axis substantially normal to the weld region;

moving the working surface relative to the weld region while maintaining the contact and applying the contact force, thereby generating a quantity of frictional heating within the welding zone; and

establishing an electrical current through the base material including or adjacent the welding zone, thereby generating a quantity of resistance heating within the welding zone;

wherein a cumulative heating of the welding zone by the frictional heating and the resistance heating, in combination with the contact force, are sufficient to cause welding of a portion of the consumable material to the surface of the base material within the welding zone.

12. A method of welding a solid consumable material to a weld region on a base material according to claim 11, wherein:

the preheating of the weld region is achieved using at least one method selected from induction heating, plasma arc heating, electric arc heating, tungsten inert gas (TIG) torch heating, laser heating and electron beam heating; and

the preheating of the portion of the consumable material is achieved using at least one method selected from induction heating, plasma arc heating, electric arc

heating, tungsten inert gas (TIG) torch heating, laser heating and electron beam heating.

13. A method of welding a consumable material to a weld region on a base material comprising:

bringing a working surface of a contact element into contact with a base surface in the weld region, the working surface being urged against the base surface by a contact force and the contact force being applied generally along an axis substantially normal to the base surface;

moving the working surface relative to the base surface while maintaining the contact force, thereby generating a quantity of frictional heating within the welding zone;

establishing an electrical current through the base material including or adjacent the welding zone, thereby generating a quantity of resistance heating within the welding zone; and

applying the consumable material to the welding zone;

wherein a cumulative heating of the welding zone by the frictional heating and the resistance heating, in combination with the contact force, are sufficient to cause welding of the consumable material to the surface of the base material within the welding zone.

14. A method of welding a consumable material to a weld region on a base material according to claim 13, wherein:

applying the consumable material to the weld region includes

contacting the weld region with a solid element prepared from the consumable material;

extruding a viscous composition prepared from the consumable material onto the weld region; or

emitting a powder composition prepared from the consumable material onto the weld region.

15. A method of welding a consumable material to a weld region on a base material according to claim 14, wherein:

applying the consumable material to the weld region includes

advancing the consumable material through an opening provided in the working surface of the contact element.

16. A method of welding a base material comprising:

bringing a working surface of a contact element into contact with the weld region on a surface of the base material under a contact force, the contact force being applied generally along an axis substantially normal to the weld region;



moving the working surface relative to the weld region while maintaining the contact and applying the contact force, thereby generating frictional heating within the welding zone; and

causing an electrical current to flow through the base material at a region including or closely adjacent the welding zone, thereby generating resistance heating within the welding zone;

wherein the frictional heating and resistance heating are generated substantially simultaneously within the welding zone to cause a cumulative heating of the weld zone, and further wherein a combination of the cumulative heating of the welding zone and the contact force is sufficient to cause welding of a portion of the base material within the welding zone.

17. A method of welding a solid consumable material to a base material according to claim 1, further comprising:

repositioning the consumable material in a first weld direction relative to the base material;

bringing the new working surface of the consumable material into contact with the base surface, the new working surface being urged against the base surface by a contact force, the contact force being applied generally along an axis substantially normal to the base surface;

moving the new working surface relative to the base surface while maintaining the contact force, thereby generating frictional heating within the welding zone;

causing an electrical current to flow through the base material, the electrical current flowing through or closely adjacent the welding zone, thereby generating resistance heating within the welding zone;

wherein a cumulative heating of the welding zone by the frictional heating and the resistance heating, in combination with the contact force, are sufficient to weld a portion of the consumable material to the base surface within the welding zone, thereby forming a second weld spot; and

withdrawing the consumable material from the base surface, thereby forming a new working surface.

18. A method of welding a solid consumable material to a base material according to claim 17, wherein:

the second weld spot at least partially overlaps the first weld spot.

19. An apparatus for welding a consumable material onto a base surface of a base material comprising:

a contact element;

a contact element housing, the contact housing arranged and configured to hold the contact element, selectively move the contact element in a plane substantially parallel to the base surface, selectively force a working surface of the contact element against the base surface in a weld zone with a contact force, the contact force being applied in a direction substantially normal to the surface,

wherein the working surface of the contact element moves while in contact with the surface to generate frictional heating;

an electrode; and

an electrical power supply, the electrical power supply being connected to the electrode and arranged to produce an electric current into the base material in the region of the weld zone;

wherein the electric current causes resistance heating of the weld zone, and

further wherein the combination of frictional heating, resistance heating and contact force is sufficient to cause semi-solid state welding of the consumable material onto the weld zone.

20. An apparatus for welding a consumable material onto a surface of a base material according to claim 19, further comprising:

a supplemental heating element, the supplemental heating element being arranged in close proximity to the contact element for preheating of the weld zone,

wherein the electric current causes resistance heating of the weld zone, and

further wherein the combination of preheating, frictional heating, resistance heating and contact force is sufficient to cause semi-solid state welding of the consumable material onto the weld zone.